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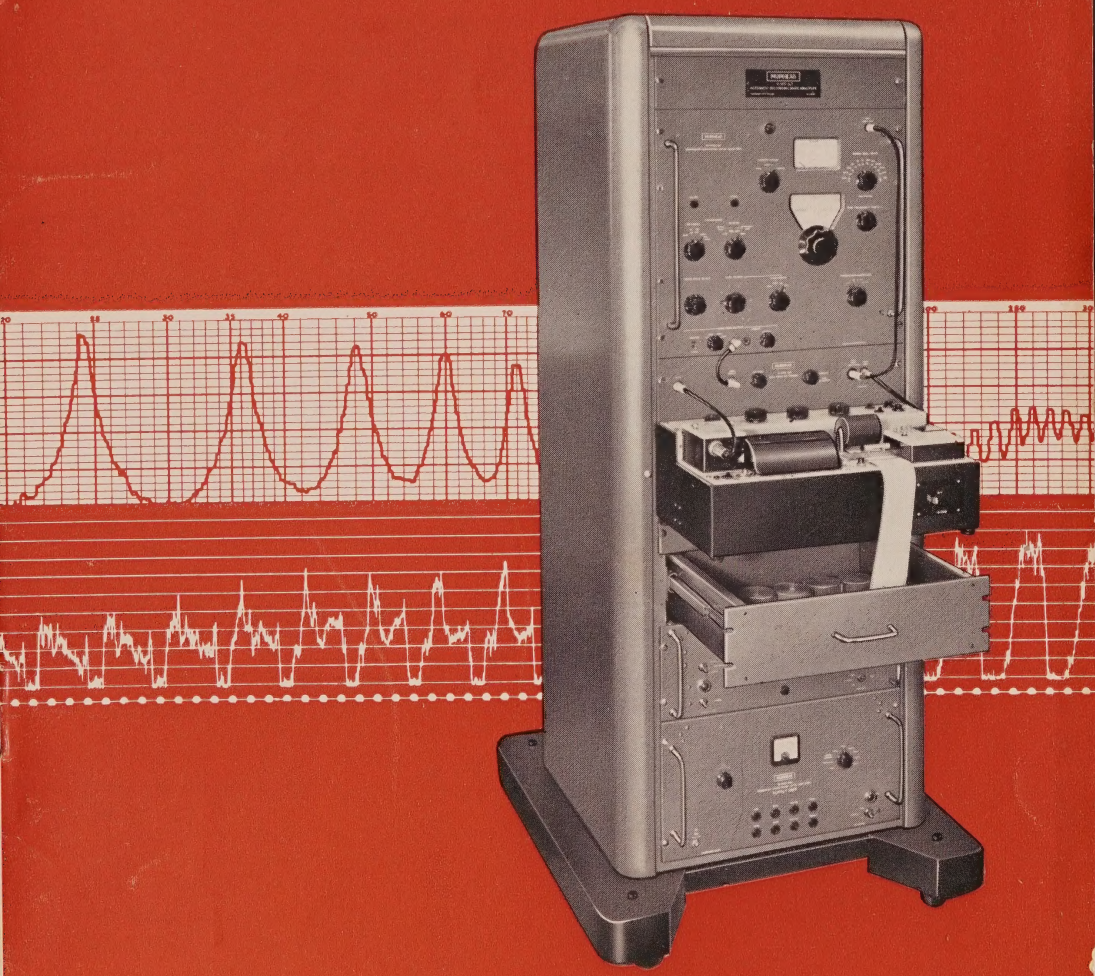

VOLUME FOURTEEN NUMBER THREE JULY 1960

MUIRHEAD

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TECHNIQUE

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VOLUME 14 NUMBER 3

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With the rising number and complexity of measurements required in present-day vibration testing the time taken in making a series of such measurements tends to become excessive and the number of man-hours involved represents a very considerable expense.

With multi-channel recording of vibrations on tape, a procedure now commonly employed, an enormous amount of time-consuming drudgery is involved in analysing these records by means of a conventional manually operated wave analyser.

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In the illustration the uppermost panel is the D-940-AM Muirhead-Pametrada Auto Analyser, immediately below which is the D-976-A Analyser Recorder. Below this is a drawer for storing spare rolls of recording paper, leads, the D-614-G Servo Amplifier and the D-940-AS Supply Unit.

RELEVANT LITERATURE

Catalogue Sheet 100: D-489-E Muirhead-Pametrada Wave Analyser and Ancillary Equipment. Catalogue Sheet 111: D-925-A Tunable Filter. Catalogue Sheet 137: D-695-A Muirhead-Wigan Decade Oscillator. Catalogue Sheet 102: D-940-A Muirhead-Pametrada Auto Analyser. Catalogue Sheet 103: D-976-A Analyser Recorder and D-614-G Servo Amplifier.

ABRIDGED CATALOGUE — 1960 EDITION

The 1960 edition of the Muirhead abridged catalogue is now available and will be mailed on request. New instruments referred to in this edition include:

K-100-A Automatic Recording Wave Analyser
Transfer Function Analyser — Ancillary Equipment
D-888-A H.F. Analyser-Oscillator
D-930-A Muirhead-Wigan Precision R.M.S. Decade Voltmeter
Newspaper Page Facsimile Equipment
D-944 Facsimile Tape Recorders

ERRATUM Technique Vol 14, No 2.
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SOME MEASUREMENTS OF INTERMODULATION AND HARMONIC DISTORTION IN HALL EFFECT MULTIPLIERS BY MEANS OF A MUIRHEAD-PAMETRADA WAVE ANALYSER

E. Cohen, M.Sc., A.Inst.P., A.M.I.E.E.*

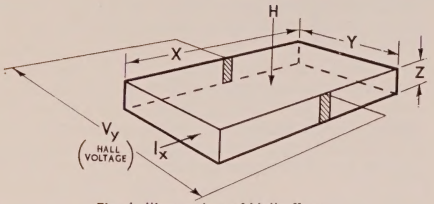


Fig. 1. Illustration of Hall effect.

INTRODUCTION

The construction of an analogue multiplier possessing the attributes of accuracy, speed and linearity demands a search for a physical relationship in which a measured quantity appears as a product of two other measurable quantities. Such a relation is found in the conduction process occurring in solid materials, and was investigated in the case of metals by the American physicist E. H. Hall, 1879.[1]

Consider a rectangular slab of material (Fig. 1) passing a current I in the x direction. In the absence of a magnetic field the equipotentials are at right angles to the lines of current flow. The application now of a uniform magnetic field H perpendicular to the slab will tend to deflect the electrons towards one side (according to the normal Lorentz force) thus producing charges at the sides which cause an electric field at right angles to the applied field. This electric field is of a direction and magnitude to balance the deflecting effect of the magnetic field. The corresponding potential difference may be detected between leads connected to the xz faces of the slab.

It may be shown that this potential is proportional to IH and inversely proportional to the thickness of the slab. The constant of proportionality is called the Hall coefficient and for normal metals, containing 10^{23} electrons/cm^3, the Hall coefficient has a very small value and the Hall effect is of little practical significance. However, due to recent advances in semi-conductor technology, advantage can be taken of much lower electron concentration in semi-conductors and an increase of the order of 10^7 in the magnitude of the Hall coefficient obtained.

THE METROPOLITAN-VICKERS HALL MULTIPLIER

A practical form of Hall multiplier, the semiconductor employed and its performance have been adequately described in the literature [2, 3, 4, 5]. Briefly, a slice of semi-conductor is inserted in the gap of a ferro-ceramic pot core assembled in such a way that I, Vy and H (produced by current flowing through a coil) are mutually orthogonal. The photographs of Figs. 2(a) and 2(b) show various views of a multiplier mounted on an international octal valve base.

For accurate multiplication a knowledge of the intermodulation and harmonic distortion introduced by the multiplier is essential. Some sources of distortion in the Hall output are:

(*a*) The presence of rectifying contacts at the current leads

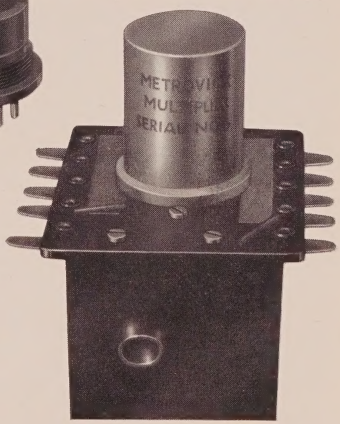
(*b*) The non-linear relationship existing between the magnetizing field and magnetic induction, i.e. the familiar B-H loop.

(*c*) The voltages induced in the current leads and Hall leads when a.c. is flowing through the coil.

(*d*) A current at the supply frequency may be injected into the Hall output apart from the normal IR drop (misalignment voltage).

Fig. 2(a).

Fig. 2(b).



Owing to the low energy gap of the semiconductor (indium arsenide) rectification effects are negligible at operating temperatures. Hysteresis is reduced by the presence of a uniform gap in the ferrite assembly which shears the B-H curve to a very thin loop; and also by, restricting the coil current swing, prevents the onset of saturation. By means of inductive compensation and suitable positioning of leads, (*c*) and (*d*) are made very small, and techniques have been developed for minimizing the misalignment voltage.

*Research Department, Metropolitan-Vickers Electrical Co. Ltd.

METHOD OF MEASUREMENT AND RESULTS

Intermodulation Distortion

To assess the degree of distortion introduced by the multiplier, it was fed with two signals, one of 265 c/s fed to a 4·5 Ω plate and the other of 177 c/s applied to the coil. This frequency was selected so as to present an impedance of 600 Ω to the oscillator output. In the absence of a magnetic field the misalignment voltage at 265 c/s with 200 mA flowing through the plate was approximately 480 μV. This figure can be reduced to a few microvolts by means of a simple potentiometric circuit.[4] The reader may refer to the block diagram and photograph of Figs. 3(a) and 3(b) for the experimental arrangement. It is, of course, desirable to know the harmonic content of the driving oscillators and amplifiers and to distinguish their relative contributions to the Hall output.

A separate measurement was made of the harmonic content of the amplifier under matched conditions with and without the Muirhead D-925-A Tunable Filter. The results are shown in Fig. 4 and it is seen that the filter attenuates the second and third oscillator harmonics 4·5 dB and 18 dB respectively. However, when considering small signals of higher order harmonics in the circuit immediately following the Hall electrodes, the insertion loss of the D-925-A Tunable Filter precludes its further use. It should be noted that as a Hall plate is a symmetrical four-pole element it is essential to feed the plate from a balanced source. Fig. 5 shows the relative magnitudes of carriers and other frequencies resulting from intermodulation distortion when two frequencies are simultaneously applied to coil and plate respectively. It appears that for a Hall multiplier which has

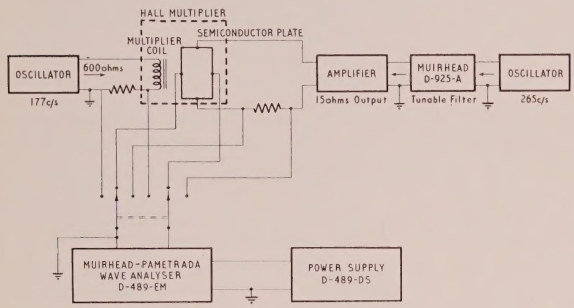


Fig. 3(a). Block Schematic of Intermodulation Distortion Measurements.

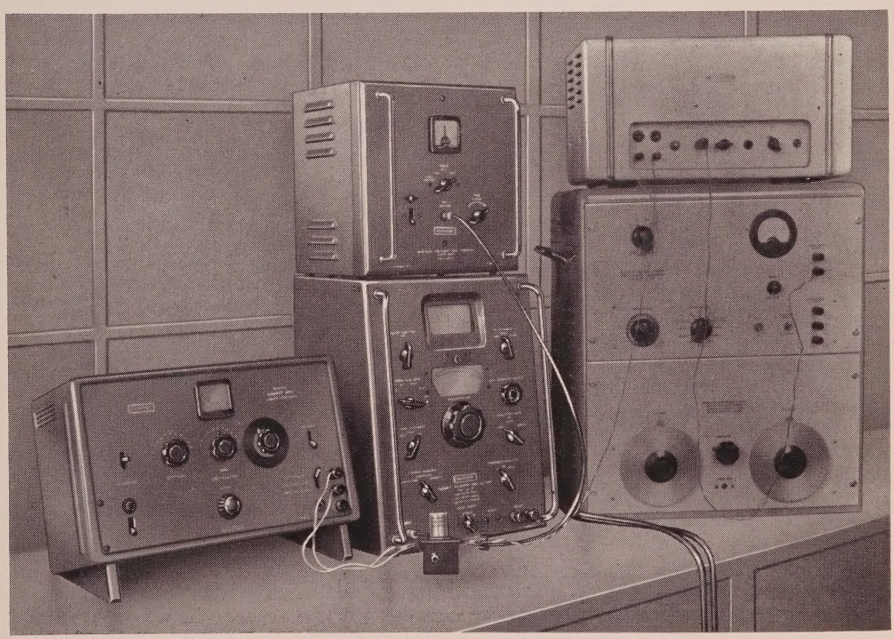


Fig. 3(b). Illustration of test apparatus: D-695-A Muirhead-Wigan Decade Oscillator (left), D-489-EM Muirhead-Pametrada Wave Analyser surmounted by D-489-DS Supply Unit (centre). The unorthodox position of the Supply Unit is only for the purpose of illustration.

been properly adjusted it is possible to attain carrier rejections 70-80 dB below double sideband amplitudes.

At the intermodulation frequency f_2+2f_1, the degree of attenuation is 62 dB. Now the second harmonic content of the coil oscillator was measured and found to be more than 60 dB below fundamental (177 c/s). It will be shown in the following section that, for frequencies above 120 c/s, measurable distortion is introduced by the B-H loop of the ferromagnetic material so that the high level of the intermodulation component at f_2+2f_1 is no doubt due to this cause. The f_1+2f_2 component arises due to the rather large spectral impurity of the plate drive amplifier as is shown in Fig. 4 and is not, therefore, due to distortion introduced by the multiplier.

It should be noted that if, in radio frequency applications, a megacycle current were supplied to the plate and audio modulation fed to the coil, inductive compensation would be unnecessary, as filtering of the induced audio-voltage would be quite simple in the Hall output. Indeed, such a simple means of generating a double sideband with suppressed carriers lends itself admirably to a communicating system using double sideband modulation as suggested by Costas.[6] Furthermore, by cross-linking another Hall multiplier, single sideband modulation may be effected as described by Cohen and Spence,[7] and Cohen.[8]

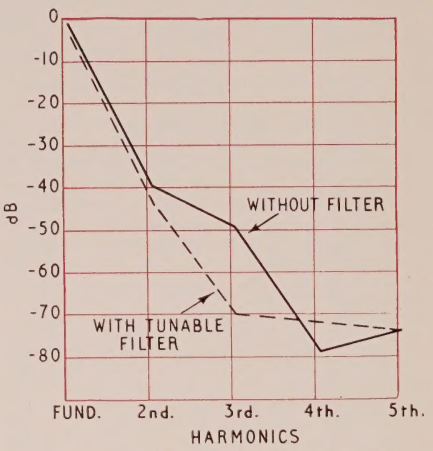


Fig. 4. Distortion in Plate Amplifier at 200 MA, 265 c/s.

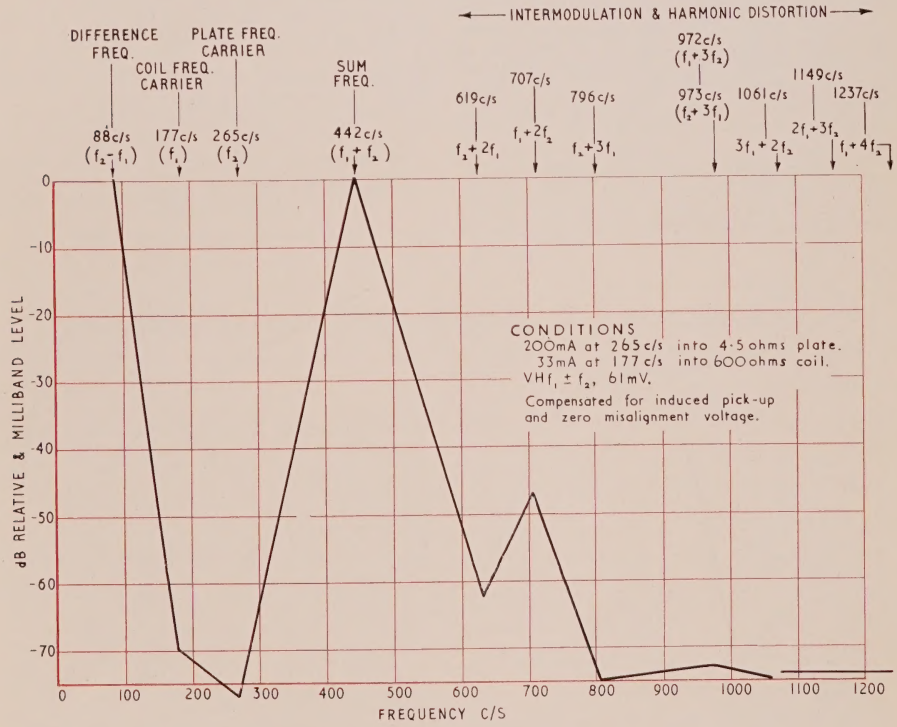


Fig. 5. Relative magnitude of distortion products in Hall circuit.

Harmonic Distortion

The following measurements were undertaken to find the contribution that a ferromagnetic core would make towards the appearance of harmonic components of the coil frequency when d.c. was flowing through the plate. The block diagram of the experimental arrangement is shown in Fig. 6. It is of the greatest importance to possess a knowledge of the components of the driving waveform and for this purpose a D-489 Muirhead-Pametrada Wave Analyser was used to measure spectral purity under matched conditions for every frequency under consideration. Fig. 7 indicates the variation of second and third harmonic currents of the driving amplifier at various frequencies, whilst Fig. 8 shows the Hall voltages that would be produced by these currents (assuming a lossless core) and also the Hall voltages actually measured.

It is difficult to ascertain the phase relationship existing between the second harmonic component of the field due to second harmonic current flowing in the coil and the second harmonic component of the field due to a non-linear B-H loop when fundamental current is flowing through the coil. However, at the higher frequencies, i.e. 120, 140 and 300 c/s (the latter is not shown), the calculated second harmonic component is much lower than the measured value, thus irrespective of phase relationships the predominant mechanism in promoting distortion at frequencies greater than 100 c/s is the non-linear response of the ferromagnetic core. At lower fundamental frequencies the relative phases must be taken into account. It is, therefore, difficult to make any predictions as to the source of distortion below 100 c/s. The provision of an oscillator with an abnormally low harmonic content would facilitate a more accurate assessment of the harmonic distortion. It should be noted that at 140 c/s the second harmonic is attenuated some 50 dB below the Hall fundamental frequency.

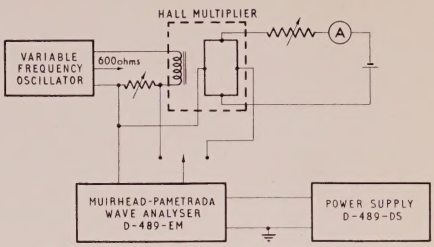


Fig. 6. Block Schematic for harmonic distortion measurements.

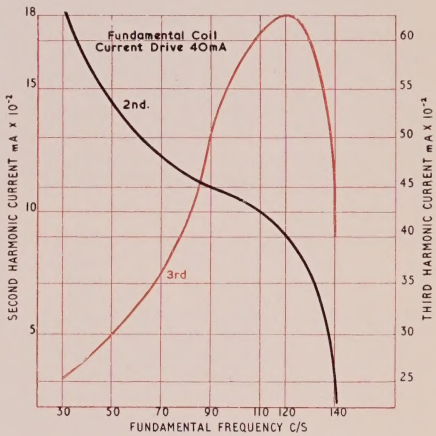


Fig. 7. Harmonic content of coil current.

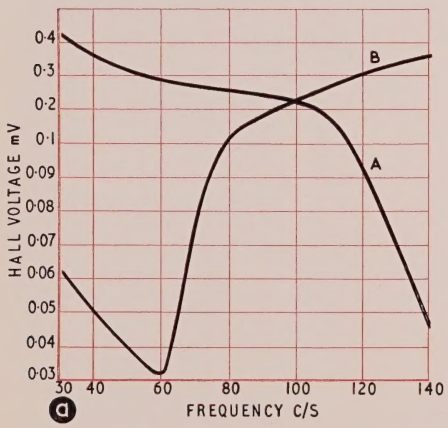


Fig. 8(a). A—Calculated second harmonoc Hall voltage assuming lossless core.
B—Measured second harmonic Hall voltage.

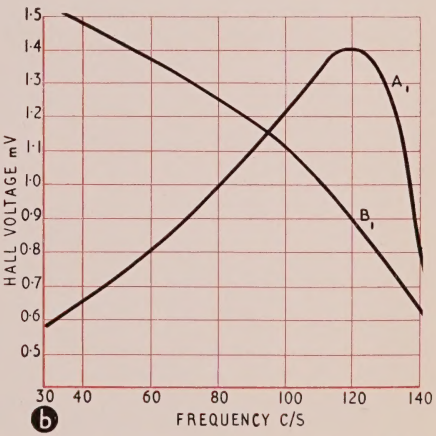


Fig. 8(b). A_1—Calculated third harmonic Hall voltage assuming lossless core.
B_1—Measured third harmonic Hall voltage.

CONCLUSION

The measurements have shown that in the frequency range under consideration measurable second and third harmonic distortion is introduced in an assembled Hall multiplier, due to the hysteresis of the core. Phase differences between a given harmonic produced by non-linear magnetic properties of the core and the harmonic content of the coil-driving waveform render an accurate assessment of the distortion in the Hall voltage difficult. Future advances in reducing hysteresis in ferro-ceramics will certainly make the Hall multiplier useful in the field of spectral analysis.

Also, by careful compensation, coil and plate circuit frequencies injected directly into the Hall output circuit can be reduced to negligible proportions. Since Hall effect devices require the use of majority current carriers only, no junctions are involved. In addition, as there are no areas of concentrated electric fields, the surfaces need not be elaborately protected.

When an electric field is induced in a semiconductor, a brief time elapses while the current carriers redistribute themselves. This relaxation time (less than 1 milli-μsec) is the only factor which limits the frequency of signals which can be satisfactorily transmitted through a Hall effect sample. Stray capacitance will tend to shunt part of the signal around the sample and will thus limit the frequency range of operation more severely.

Current Hall multipliers present engineers with invaluable circuit elements which may simplify a host of electronics operations for research and industry, and satisfy the requirements for such circuit applications as choppers, analogue multipliers, power meters, isolators and power stabilization circuits.

ACKNOWLEDGMENTS

The author wishes to thank Mr R. P. Chasmar for his kind comments in the preparation of this paper, and Sir Willis Jackson, F.R.S., Director of Research and Education, Metropolitan-Vickers Electrical Co. Ltd, for permission to publish.

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MEASUREMENT OF SYNCHRONIZING TIME OF SYNCHROS

by J. G. Dixon*

When a synchro torque transmitter and a corresponding torque receiver are connected as shown in Fig. 1 and their rotors are energized, smooth movement of the transmitter rotor will produce a corresponding movement of the receiver which will follow with an angular accuracy of one degree or better. However if a sudden movement be imparted to the transmitter rotor, the rotor of the receiver will aline itself with that of the transmitter but only after performing several oscillations of decreasing amplitude. The overshoot is caused by the rotor inertia coupled with the drop in torque when approaching alinement.

Specification Mil-S-20708A lays down that, when connected as described, a synchro torque receiver shall synchronize or aline itself from an initial displacement of 30° in one second, and from an initial displacement of 177° in two seconds. Measurement of this relatively small time interval with the aid of a stop watch would obviously be highly inaccurate. Apart from the human factor of differing operator response time, the instant at which the receiver completely comes to rest would be extremely

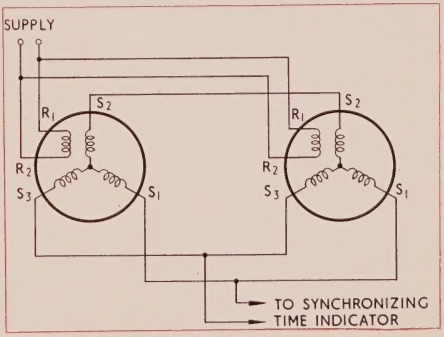

Fig. 1. Synchro connexions.

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difficult to detect with any degree of certainty. If an oscilloscope was used to display a voltage corresponding to the misalinement of the rotors and the X-ordinate calibration was used to determine the time interval from the instant of 'switch-on' to the time when the receiver ceased to oscillate, more accurate and repeatable results would be obtained, but the method is complicated, requiring an elaborate oscilloscope with a long persistence tube and is not suited to production testing.

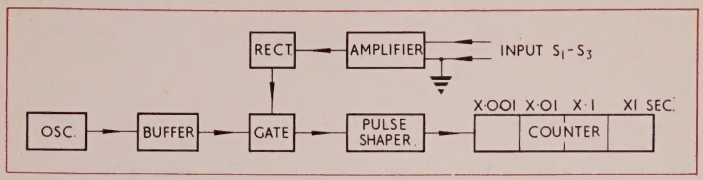
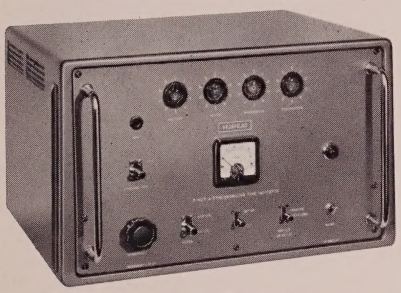


Fig. 2. Block schematic of Synchronizing Time Indicator.

The Synchronizing Time Indicator, which is the subject of this article, has been developed to measure this time interval with reasonable accuracy and repeatability. The



D-928-A Synchronizing Time Indicator.

instrument (see Fig. 2) consists basically of four parts: a 1000 c/s oscillator, a four stage 'Dekatron' counter, a tuned amplifier and the requisite power supplies. The principle of operation is as follows: A 1000 c/s signal is generated by the oscillator, the output of which is coupled through an electronic switch or gate to the counter. Whilst the electronic switch is 'on' the counters will operate and count the cycles of the oscillator and thereby indicate time in thousandths, hundredths, tenths and units of seconds, until the electronic switch is turned 'OFF'. The electronic switch is controlled by the line voltage existing between S_1 and S_3 of the synchro under test which, after frequency selective amplification, undergoes rectification before being used to set the electronic switch to the 'ON' position.

Provision is made for adjusting the frequency selective characteristic to suit either 60 c/s or 400 c/s elements and a sensitivity switch makes adjustments to accommodate 26V or 115V synchros, a further manual sensitivity control is included.

Two methods of operation are possible, with or without mounting the receiver in a dial. In the first method the receiver is mounted in a dial and the rotors of the two synchros are alined (a procedure simplified by the inclusion in the instrument of a small voltmeter). If, then, the receiver rotor is displaced by the required angle and the system is energized, the counter will indicate the time taken for the receiver to aline itself. The counter can then be reset and the procedure repeated.

In the second method the receiver is simply clamped in a fixture without any angular calibration. After alining the transmitter and receiver with the system energized, the transmitter is displaced by the required angle and the receiver follows. The system is de-energized, the counter reset and the transmitter returned to its original position. On re-energizing, the synchronizing - time will be indicated.

Due to the necessity of smoothing the rectified signal before its application to the electronic switch a time constant is introduced which will delay the 'switch off' point. If allowance is made for this time constant, which is of the order of 50 milliseconds, the accuracy is within a few milliseconds. The time constant does, however, ensure that the counters do not switch 'OFF' for the short interval of time on each occasion that the receiver swings through its position of synchronism.

Fig. 3 indicates the general form of the voltage wave existing between lines S_1 and S_3 from the moment of switching on until some time after the position of synchronization has been obtained. It will be noticed that in general the voltage waveform does not reduce to zero but remains at some small but finite value; this is due in part to the small inherent error in alinement, which will occur due to rotor friction, the remainder being synchro residual and harmonic voltages. It is this factor which makes the end point difficult to determine by visual means. However, by adjustment of the sensitivity control the timer may be set so that it switches when one degree misalinement, the maximum permissible allowable error, exists between the transmitter and the receiver and will operate consistently at this pre-determined level, this being the important feature that ensures excellent repeatability.

In general the instrument is simple to operate by unskilled personnel, has a good long term stability due to the fully stabilized power supplies and has proved to be extremely reliable and consistent in operation. The instrument may, of course, be useful for applications other than the measurement of synchronizing time for synchro testing, where it is required to measure time intervals up to ten seconds.

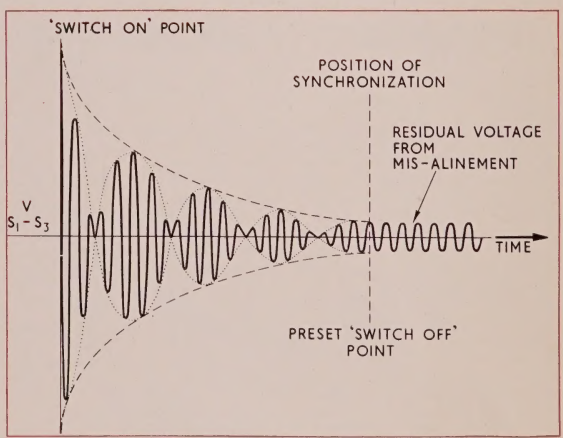


Fig. 3. Voltage waveform between lines S1-S2 during synchronizing period.

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